Biogeochemical and nutrient removal patterns of created riparian wetlands: Seventh-year results (2000)

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Introduction

As part of a long-term, large-scale experiment on self-design, two wetland basins at The Olentangy River Wetland Research Park were set up as a planting experiment, i.e., one basin was planted in 1994 with 2400 individuals of macrophytes representing 12 species while a second wetland basin remained unplanted (Mitsch et al., 1998). In the 7 years of wetland development since that planting, the basins have gone through 7 growing seasons that have been characterized as follows:

• Year 1 (1994) – Wetland 1 (W1) was planted in May with Wetland 2 (W2) as unplanted control. Essentially both basins were algal ponds with few macrophytes.

• Year 2 (1995) – Wetland 1 plants developed, particularly around the perimeter to about 13% macrophyte cover in August, compared to essentially no macrophyte cover in Wetland 2. Floods in late June and early August brought in large carp with waters remaining turbid through much of the rest of the year.

• Year 3 (1996) – Wetland 1 continued to develop in vegetation cover with about 39% cover. Unplanted Wetland 2, particularly after spring drawdown in both wetlands to install sedimentation markers, developed to about 35% macrophyte cover by August, essentially catching up with the planted wetland within 3 growing seasons.

• Year 4 (1997) – Macrophyte growth continued to increase in both wetlands with about 54% cover in Wetland 1 and 58% cover in Wetland 2.

• Year 5 (1998) – Macrophyte cover was similar in the two basins but Wetland 2 began to be dominated by highly productive *Typha* spp. while Wetland 1 still had a wider diversity of cover and was not dominated by *Typha* spp. In other words, Wetland 1 plant cover was now more diverse.

• Year 6 (1999) – Wetland 2 was dominated by *Typha* while Wetland 1 continued to be dominated by 3-4 of the planted species.

• Year 7 (2000) – Similar to 1999 except muskrats developed in the winter of 2000 and began to have a dramatic effect on ecosystem function.

This study reports water quality results for the 7th year (2000). Other studies of the water quality of these wetlands are reported for Year 1 (Mitsch et al., 1995), Year 2 (Wehr and Mitsch, 1996; Mitsch and Nairn, 1996; Nairn and Mitsch, 1997), Year 3 (Mortensen et al., 1997; Mitsch and Carmichael, 1997; Nairn and Mitsch, 1997; Vorwerk and Mitsch, 1998), Year 4 (Mitsch and Montgomery, 1998; Spieles and Mitsch, 1998), Year 5 (Mitsch et al., 1999),and Year 6 (Mitsch et al., 2000). Two undergraduate honors theses (Wehr, 1995; Vorwerk, 1997), one Master's thesis (Harter, 1999), two Master's theses from Europe (Mortensen and Lanzky, 1996; Kang, 1999) and four dissertations

Table 1. Water quality sampling at Olentangy River Wetland site in 2000.

Sample frequency	# Sampling stations	Period in 2000	Equipment	Parameters measured
twice daily	3 (inflow-W1; two outflows)	Jan-Dec	YSI probe	temperature dissolved oxygen pH redox conductivity
			Hach turbidimeter(Lab)	turbidity
weekly	7 (river; 1 inflow-W1; 2 middles; 2 outflows; swale)	Jan-Dec	YSI probe	temperature dissolved oxygen pH conductivity
			Hach turbidimeter(Lab)	turbidity
			LACHAT QuikChem IV(Lab)	total phosphorus soluble reactive P $NO_3 + NO_2$

(Nairn, 1996; Spieles, 1998; Liptak, 2000; Ahn, 2001) have also investigated aspects of water quality at the site. Four journal articles (Mitsch et al., 1998; Kang et al., 1998; Nairn and Mitsch, 2000; Spieles and Mitsch, 2000) have been published on water quality changes through these experimental wetlands.

Methods

A summary of the water quality monitoring protocol for the two experimental wetlands in 2000 is shown in Table 1. Locations of the various sampling stations are shown in Figure 1.

Weekly Sampling

Weekly water sampling, instituted in late April 1994 continued through 2000. Samples were taken at 7 stations in 2000 as in the previous 4 years. One 1000 ml sample was collected at each of the 7 sites. Water samples were taken to the Ecosystem Analytical Laboratory at Ohio State University where subsamples were filtered and frozen for later measurement of soluble reactive phosphorus. Unfiltered samples were preserved with concentrated H_2SO_4 (2 ml/liter sample) and frozen for later analysis of total phosphorus and nitrate+nitrite (NO_3+NO_2). A raw sample was also stored for any new or additional analyses to be added. Sample preparation and preservation was completed within 48 hours of original collection.

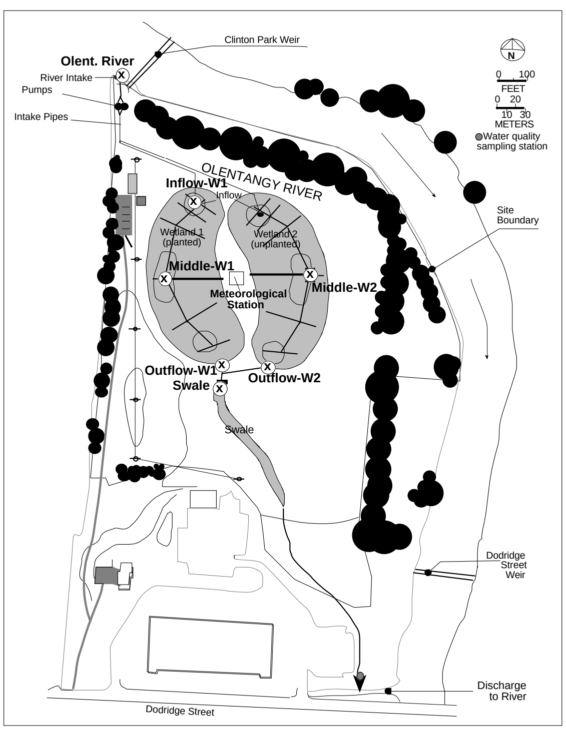

Figure 1. Location of water sampling stations used in 2000 for the experimental wetlands.

Daily Sampling

Two-per-day water sampling, also initiated in 1994, continued through 2000 by the staff and students of the Wetlands Program at Ohio State University. Inflow of Wetland 1 (assumed after several studies to represent the inflow to both basins) and the outflows of Wetland 1 and Wetland 2 were monitored in 2000 for temperature, dissolved oxygen, pH, conductivity, and redox with a YSI probe. Instruments were calibrated and checked for battery power frequently. Each time a 100-ml Nalgene bottle was used to take a sample for later measurement of turbidity in the lab at each of the three stations.

Sample Analysis

For all laboratory analyses in 2000, Standard Methods for the Examination of Water and Wastewater, 17th Edition (APHA, 1989) and EPA Methods for Chemical Analysis of Water and Wastes (U.S. EPA, 1983) were followed. Total phosphorus, soluble reactive phosphorus, and nitrate+nitrite were analyzed on a quarterly or more frequent basis on a Lachat QuikChem IV automated system and Lachat methods (U.S. EPA, 1983). Both total phosphorus and soluble reactive phosphorus methods employed the ascorbic acid and a molybdate color reagent method. For soluble reactive phosphorus and total phosphorus, total phosphorus samples were first digested by adding 0.5 ml of 5.6N H_2SO_4 and 0.2 g NH_3SO_4 to 25 ml of sample and exposing the samples to a heated and pressurized environment for 30 minutes in an autoclave. Nitrate+nitrate, run on the Lachat QuikChem IV automated system, used the cadmium reduction method.

Results and Discussion

Water quality results for 2000 weekly and two-per-day sampling are summarized in Table 2 while percent change through the wetlands and statistical significance are summarized in Table 3.

Nitrate-Nitrogen

Nitrate-nitrogen concentrations in the inflow and river in 2000 were almost double what they were the past two years but similar to 1996 and 1997. Nitrate concentrations decreased overall in 2000 by 33% in Wetland 1 and by 44% in Wetland 2. Differences between wetlands were not significant (α=0.05). In 1999 nitrates decreased by 30% in Wetland 1 and 33% in Wetland 2. Retention in 1998 was almost the same at 33 % in Wetland 1 and 39% in Wetland 2 which had doubled from 1997 when only 18% was retained in Wetland 1 and 17% in Wetland 2. There were 33 and 25% decreases respectively for the two wetlands in 1996. Nitrate-nitrogen decreased in a very similar and almost linear pattern through the two wetlands.

Soluble Reactive Phosphorus

For the fifth year in a row, a seasonal pattern was observed with well-defined decreases in SRP from inflow

Table 2. Summary of water quality measurements at Olentangy River experimental wetlands, 1996 through 2000. Two -per-day sampling refers to dawn-dusk sampling done almost every day that water is flowing. Numbers are average ± std. error (# of samples).

Parameter	Year	Olent. River	Inflow	Middle-W1	Middle-W2	Outflow-W1	Outflow-W2	Swale
Total P, μg-P/L	1996	185±15 (40)	191±18 (30)	85±11 (33)	77±9 (34)	68±8 (34)	64±9 (35)	62±9 (33)
	1997	149±16 (46)	146±17 (45)	99±7(39)	113±13 (38)	125±20 (41)	120±12 (43)	94±7 (44)
	1998	244±28 (47)	186±16 (46)	129±15 (47)	133±14 (47)	98±10 (47)	98±11 (47)	31±7 (47)
	1999	194±35 (48)	126±11 (44)	99±11 (43)	138±22 (41)	92±17 (44)	76±12 (45)	70±9 (45)
	2000	159±19 (49)	138±12 (48)	137±30 (41)	148±32 (40)	72±16 (46)	90±19 (47)	86 ±14 (46)
SRP, μg-P/L	1996	58±8 (38)	70±11(29)	19±4 (33)	16±4 (33)	8±1 (33)	9±2 (33)	9±2 (32)
	1997	50±6 (48)	67±12 (47)	23±3 (40)	25±3 (39)	26±3 (37)	23±3 (40)	37±13 (39)
	1998	89±11 (47)	82±10 (46)	45±9 (47)	45±9 (47)	27±6 (47)	31±7 (47)	31±7(47)
	1999	97±10 (47)	94±10 (43)	46± 8 (45)	33±6 (44)	27±4 (47)	24±4 (46)	23±4 (48)
	2000	83 ±9 (46)	82±9 (46)	27±4 (39)	27±4 (40)	19±4 (45)	27±5 (46)	31±6 (44)
$NO_3 + NO_2$, mg-N/L	1996	4.60±0.41 (38)	4.42±0.42 (29)	3.08±0.38(34)	2.89±0.32(34)	2.97±0.40(34)	3.30±0.38(34)	3.19±0.47(31)
	1997	4.89±0.97 (48)	4.23±0.75 (47)	2.92±0.62 (39)	3.02±0.69 (39)	3.51±0.71 (42)	3.55±0.71 (42)	3.45±0.71 (44)
	1998	2.79±0.39 (47)	2.72±36 (46)	2.06 ±0.35 (47)	2.02 ±0.33 (47)	1.83±0.32 (47)	1.67±0.34 (47)	1.82±0.33 (45)
	1999	1.94±0.24 (47)	1.91±0.24 (44)	1.51±0.29 (42)	1.46±0.25 (44)	1.33±0.28 (45)	1.28±0.24 (45)	1.20±0.23 (47)
	2000	4.74±0.63 (49)	4.35±0.48 (48)	3.63±0.55 (41)	2.93±0.44 (42)	2.85±0.62 (45)	2.42±0.34 (46)	2.68±0.62 (43)
Turbidity, NTU [1]	1996		35±3 (319)			21±2 (404)	20±2 (407)	
	1997		28±2 (453)			26±2 (426)	27±2 (447)	
	1998		25±2 (446)			16±1 (459)	16±1 (462)	
	1999		25±2(493)			19±1 (524)	20±1 (521)	
	2000		29±2 (436)			17±1 (442)	19±1 (449)	
D.O., mg/L [1]	1996		9.69±0.19 (278)			10.55±0.21(336)	10.48±0.18(338)	
	1997		9.90±0.2 (454)			11.38±0.28 (412)	11.32±0.29 (430)	
	1998		9.40±0.14 (430)			11.98±0.26 (433)	11.66±0.25 (436)	
	1999		8.70±0.15 (463)			9.12±0.24 (486)	8.59±0.21 (489)	
	2000		9.96±0.18 (417)			10.81±0.24 (432)	9.46±0.21 (431)	
Temp, °C [1]	1996		14.9±0.5 (302)			15.5±0.4 (373)	15.7±0.4 (373)	
	1997		13.2 ±0.4 (476)			13.7±0.4 (443)	13.7±0.4 (464)	
	1998		14.6±0.4 (456)			15.0±0.4 (471)	15.1±0.4 (475)	
	1999		14.9±0.4 (488)			14.8±0.4 (512)	14.6±0.4 (509)	
	2000		13.6±0.4 (478)			14.5±0.4 (487)	14.3±0.4 (486)	
Cond., μS/cm [1]	1996		535±6(282)			452±5(349)	454±5(350)	
	1997		621±7 (401)			576±7 (364)	593±7 (385)	
	1998		539±6 (450)			487±5 (462)	502±6 (467)	
	1999		550±8 (488)			527±8 (513)	533±8 (512)	
	2000		454±5 (479)			421±4 (485)	441±5 (486)	
pH [1]	1996		7.91±0.02(300)			8.17±0.03(367)	8.19±0.03(368)	
	1997		7.94±0.03 (443)			8.24±0.04 (412)	8.20±0.04 (431)	
	1998		8.18±0.04 (365)			8.47±0.04 (374)	8.38±0.04 (375)	
	1999		7.74±0.02 (480)			7.87±0.03 (502)	7.80±0.02 (502)	
	2000		7.73±0.01 (425)			7.93±0.02 (438)	7.76±0.02 (433)	
Redox, mV[1]	1996		394±4(213)			387±3(263)	384±3(265)	
	1997		433±3 (338)			433±3 (352)	430±4 (377)	
	1998		333±6 (440)			309±6 (450)	307±6 (456)	
	1999		302±7 (436)			283±7 (460)	281±7 (457)	
	2000		289±2 (376)			274±2 (386)	283±2 (383)	

[1] two-per-day sampling

to outflow during the summer months and less obvious patterns in spring and winter but with two-thirds of the SRP removed by the wetland in 2000. On average, SRP decreased by 77 and 70% in Wetlands 1 and 2 respectively in 2000. Rates were similar to the 71 and 75% in 1999. Rates were 67% in Wetland 1 and 63% in Wetland 2 in 1998. In 1997, SRP decreased by 61% in Wetland 1 and 66% in Wetland 2. In 1996, the respective decreases were 89 and 87%.

Outflow concentrations of SRP averaged 19-27 μg-P/L in 2000, lower than the 24-27 μg-P/L in 1999, the 27-31 μg-P/L in 1998 and the 23-26 μg-P/L seen in 1997. Concentrations in 1996 in the outflow were extremely low at 8-9 μg-P/L.

Table 3. Water quality changes (+ indicates increase through wetland) and statistical significance at Olentangy River experimental wetlands, 1999-2000. W1 = planted wetland; W2 = unplanted wetland; In = inflow; Out = outflow.

Parameter and year	% change W1	% change W2 (+ = increase; - = decrease)	Paired t-test, p-value In v. Out W1	In v. Out W2	Out W1 v. Out W2
Temp 99	-1.1	-2.1	nd	nd	0.0070
Temp 00	+6.0	+5.1	0.0000	0.0134	0.0000
Turbidity 99	-24.3	-18.2	0.0001	0.0070	0.0044
Turbidity 00	-42.7	-35.2	0.0000	0.0000	0.02751
D.O. 99	+4.9	-1.2	nd	0.0438	0.0001
D.O. 00	+8.5	-5.0	0.0000	0.0010	0.0000
pH 99	+ 1.7	+0.7	0.0001	0.0020	0.0001
pH 00	+2.7	+0.4	0.0000	0.0040	0.0000
Cond 99	-4.2	-3.1	0.0002	nd	0.0014
Cond 00	-7.2	-2.9	0.0000	0.000	0.0000
Redox 99	-6.3	-6.8	0.0001	0.0001	nd[1]
Redox 00	-5.1	-2.3	0.0000	0.0000	0.0000
Total P 99	-27	-40	0.0128	0.0001	nd
Total P 00	-47	-34	0.0000	0.0184	nd
SRP 99	-71	-75	0.0001	0.0001	nd
SRP 00	-77	-67	0.0000	0.0000	nd
$NO_3 + NO_2$ 99	-30	-33	0.0001	0.0001	nd
$NO_3 + NO_2$ 00	-34	-44	0.0004	0.0000	nd

[1] nd = no significant difference at $\alpha = 0.05$

Total Phosphorus

Total phosphorus decreased by an average of 47% in Wetland 1 (where primary productivity was highest) and by 34% in the *Typha* wetland 2. Retention percentages flip with a lower retention last year (27%) in Wetland 1 and a higher rate last year in Wetland 2 (40%) in Wetland 2. In contrast, total phosphorus (TP) concentrations decreased by 48 and 47% respectively for Wetland 1 and Wetland 2 in 1998. The decreases through the basins were significant (α=0.05) but the two basins were not significantly different in phosphorus retention. TP decreased by 14% in Wetland 1 and 18% in Wetland 2 in 1997, but neither of these decreases was significant (α = 0.05).

Outflow concentrations were 72 and 90 µg-P/L in 2000 for Wetlands 1 and 2 respectively, compared to 92 and 76 µg-P/L in 1999. Concentrations were slightly lower than the 98 µg-P/L in both wetlands in 1998. The outflow was 125 µg-P/L in Wetland 1 and 120 µg-P/L in Wetland 2 in 1997 and 68 and 64 µg-P/L respectively in 1996. The data indicate the wetland has shown increased phosphorus removal performance since 1997.

Turbidity

Inflow turbidity averaged 29 NTU in 2000 and 25 NTU in 1998 and 1999. Turbidity decreased by 43 and 35% respectively in Wetlands 1 and 2 compared to 24 and 18% in 1999. So suspended solid removal was better in 2000 in both wetlands and similar to retentions of 36% in Wetland 1 and 37% in Wetland 2 seen in 1998.

Dissolved Oxygen

Dissolved oxygen continued to display significant diurnal patterns coupled to primary productivity and respiration and overall changes from inflow to outflow, taking into account dawn and dusk readings, were much different than in 1999. Dissolved oxygen increased more in Wetland 1 and decreased more in Wetland 2 in 2000 (+8.5% in Wetland 1 and -5% decrease in Wetland 2). Overall, dissolved oxygen increased from 10.0 mg/L in the inflow to 10.8 mg/L in Wetland 1 outflow. But it decreased for the second year in a row in Wetland 2, this time to 9.5 mg/L. The increase in Wetland 1 and the decrease in Wetland 2 were both significant (a = 0.05). Dissolved oxygen averaged 12.0 and 11.7 mg/L respectively for Wetlands 1 and 2 outflows in 1998 and 11.4 and 11.3 mg/L respectively for Wetlands 1 and 2 outflow in 1997. These are early signs that oxygen demand is increasing in the sediments, particularly in Wetland 2.

Temperature

Water temperature increased significantly in both basins, primarily due to the removal of vegetation by muskrats in the winter of 2000. This was after several years of decreasing temperatures at the outflow. Temperature had actually decreased through the wetlands by 1 to 2 % in 1999 although the changes were not significant. Outflow temperatures were significantly different (α=0.05) in 2000. Wetland 2 outflow was cooler on average by 0.2°C just as it was in 1999.

Conductivity

Conductivity decreased by 3-7% through the wetlands, with the higher decrease in Wetland 1. The two wetlands were significantly different from one another in 2000. In 1999 conductivity decreased by 3 to 4%. Wetland 1 changed from 1999 to 2000 but Wetland 2 did not. There were higher decreases of 10% in Wetland 1 and 7% in Wetland 2 in 1998 which were also significant (α=0.05). There was an average of 5 to 7% decrease in dissolved materials in 1997 and a 15% decrease in 1996. The decrease in dissolved ion concentrations from inflow to outflow, particularly in the growing season, is due to precipitation of calcium carbonate and other minerals caused by high pH that, in turn, is caused by the high water column productivity. The removal of vegetation by muskrats caused higher productivity in Wetland 1, leading to more precipitation of dissolved ions.

pH

pH of the inflow waters from the Olentangy River averaged 7.73 in 2000, 7.74 in 1999, 8.18 in 1998, 7.94 in 1997, and 7.91 in 1996. Outflows of Wetlands 1 and 2 were significantly higher than the inflow (2.7 and 0.4% higher respectively) in 2000. Wetland 1 pH increase was significantly higher than that in Wetland 2 (α=0.05), the same situation was seen in 1998 and 1999.

Redox

Redox potential was significantly different between the two wetlands for the first time in several years. Redox decreased by 5.1% in Wetland 1 and 2.3% in Wetland 2. Inflow averaged 289 mv in 2000, a little lower than the 302 mv in 1999. Outflows of Wetlands 1 and 2 were 274 and 283 mv respectively, essentially the same as in 1999. The two wetlands did show significant decreases in redox from inflow to outflow as in 1999.

Conclusions

Differences between Wetland Basins in 7 Years

Water quality data have now been collected at the Olentangy River Wetland experimental wetlands for seven years. Of the 6 basic water quality parameters consistently measured over that period, all 6 are now significantly different for the first time. There were 5 that were significantly different between the two wetlands in 1999 when divergence began. Only 2 parameters showed significant differences between the two wetland basin outflows in 1998, and 1 parameter in 1997. The seventh year results (2000) reported here suggest that a clear divergence has occurred as a result of the *Typha* monoculture in Wetland 2 that began in 1999, a more diverse plant community in Wetland 1, and the invasion of large numbers of muskrats in the winter of 2000. The two experimental wetlands were more divergent biochemically than ever before in 2000.

Nutrient Retention

Nutrient concentrations continued to decrease through the wetlands, the 7th straight year where that occurred. Nitrate-nitrogen decreased by an average of 39% in the two basins and total phosphorus decreased by an average of 40%. The wetlands appear to be getting more effective in retaining nitrate-nitrogen in the past few years, while total phosphorus retention has decreased somewhat since the early years. For example, Mitsch et al. (1998) reported that total phosphorus was reduced by averages of 69, 55, and 65% for 1994, 1995 and 1996 in the experimental wetlands.

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